Hadronic contributions to the anomalous magnetic moment of the muon

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(RBC and UKQCD collaborations)

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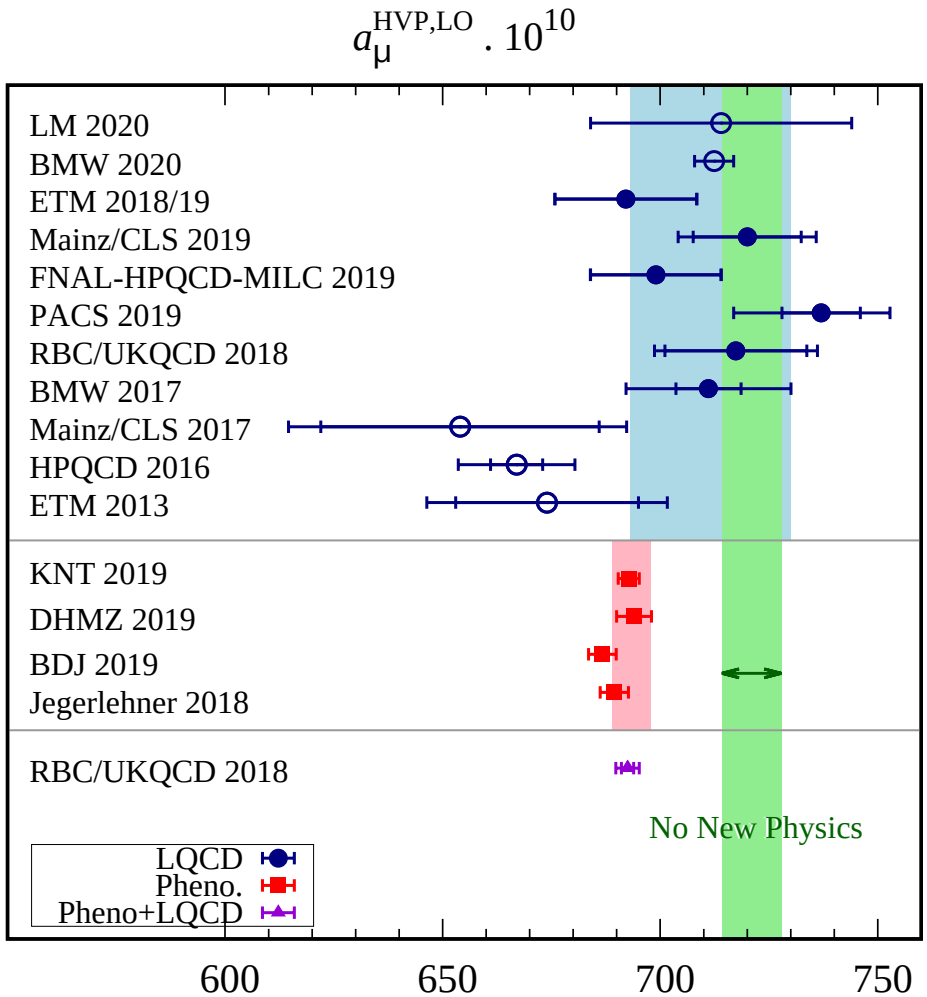
- Persisting $3-4\sigma$ tension between the standard model theory and BNL measurement for muon g-2 $\Rightarrow$ Possible hint for new physics

- FNAL E989 will improve experimental precision of 0.54 ppm by a factor of four in the coming years. First results very likely by the end of this year.

- Current experimental uncertainty balanced with theory $\Rightarrow$ theory uncertainty needs to be improved

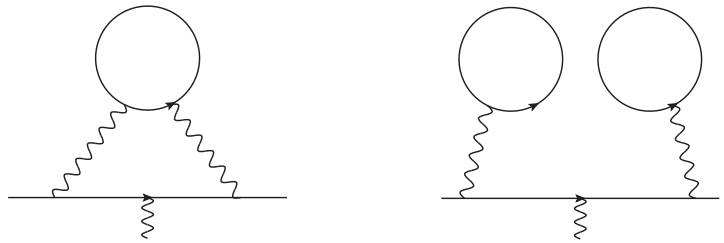
- Theory uncertainty is dominated by two non-perturbative QCD contributions, the hadronic vacuum polarization (HVP) and the hadronic light-by-light scattering (HLbL) with similar individual uncertainties.

Hadronic vacuum polarization:

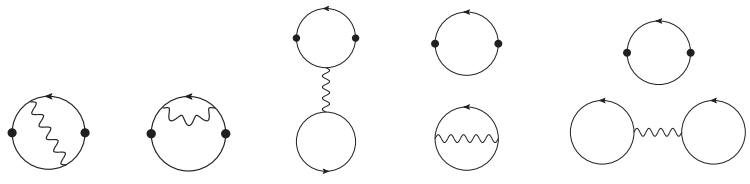


Source: Theory Initiative Whitepaper arXiv:2006.04822

Isospin-symmetric limit:



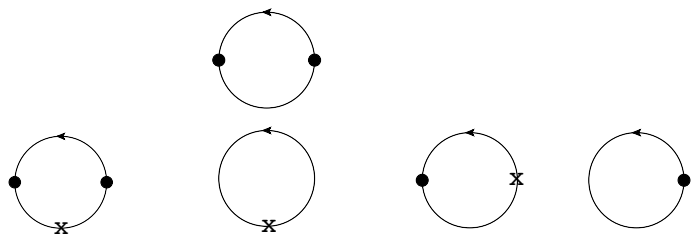
QED corrections:



(a) V (b) S (c) T (d) D1 (e) D2

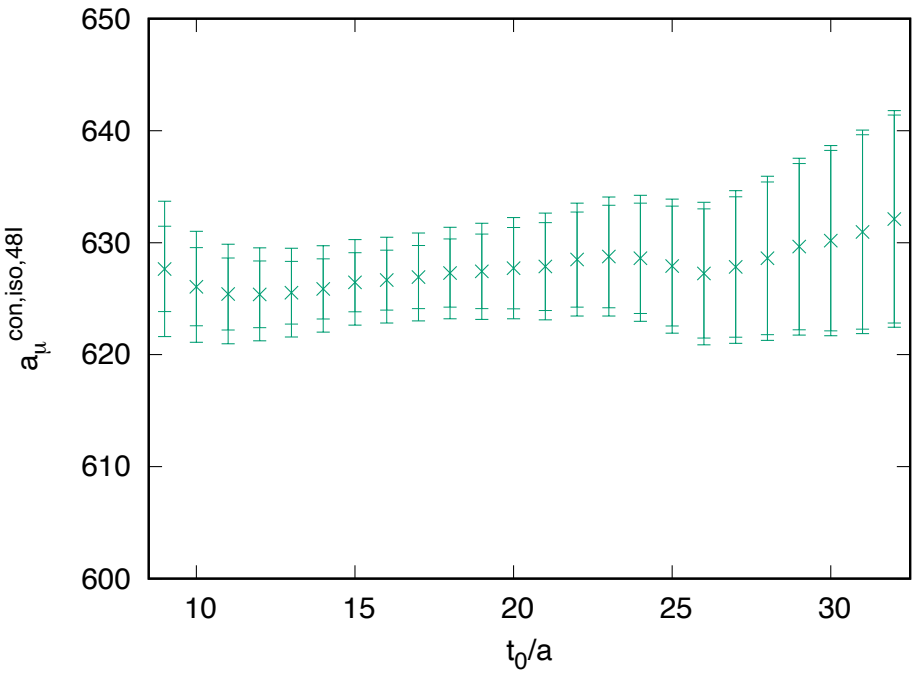
(f) F (g) D3

Strong isospin-breaking corrections:



(a) M (b) R (c) O

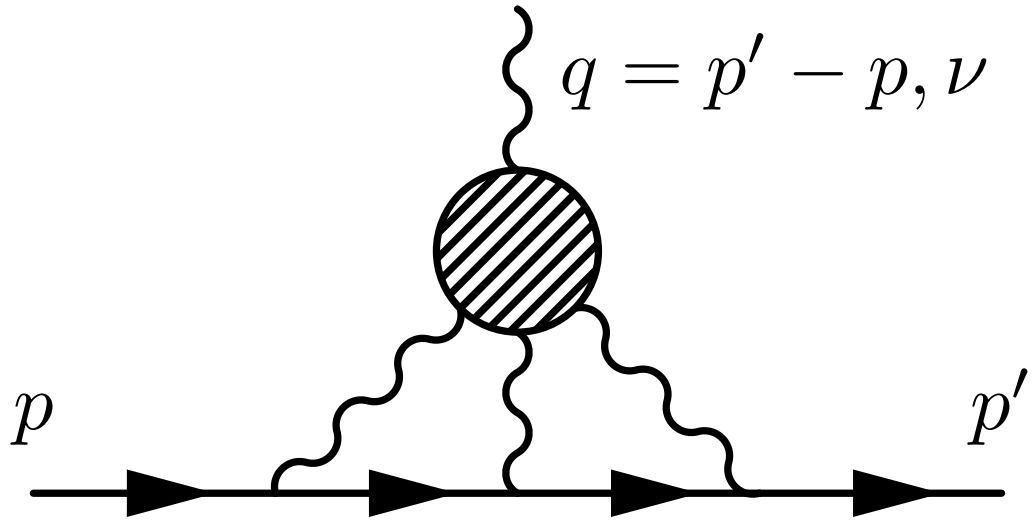
- Need to calculate at 1-2 per-mille precision to match experimental precision after Fermilab E989. Current status: first results around 1%.
- Further error reduction by factor of 10 is a challenging task for the next 5-10 years.
- Many improvements for improved statistical and systematic control have already been developed, e.g., improved bounding method (RBC/UKQCD) for light-quark connected isospin symmetric contribution:



Future:

- Need statistics dominated error budgets!
- Simulations at finer lattice spacings a with $a^{-1} \approx 5$ GeV desired! See related computational LoI with algorithmic developments to accelrate this.
- Within RBC/UKQCD, simulations are already only at physical pion mass, so no chiral extrapolation needed. High-precision control of QED and SIB effects crucial.
- Combined R-ratio/lattice QCD approaches as proposed by RBC/UKQCD 2018 may play a crucial role to scrutinize and improve the estimates. Euclidean time windows also serve as tools for cross-checks.

Hadronic light-by-light scattering:



First ab-initio result this year (RBC/UKQCD PRL124(2020)132002):

$$a_\mu^{\mathrm{HLbL}} 10^{10} = 7.87(3.06)_{\mathrm{stat}}(1.77)_{\mathrm{sys}} \tag{1}$$

For this quantity it will suffice to reduce the uncertainty to O(10%) in the next 5-10 years.

Future:

- Our previous result used a finite-volume regulator for the photons, will focus on infinite-volume photons coupled to finite-volume quark correlators.
- This removes large power-law finite-volume errors but requires special attention to control statistical uncertainties originating from long-range contributions.
- For this we will re-use successful ideas of our HVP projects with regards to full low-mode averaging using a locally coherent Dirac eigenmodes representation.
- We aim to also calculate the long-distance part of the neutral pion-pole contribution separately to further reduce the statistical noise and finite-volume dependence.
- In the current calculation some sub-leading diagrams are only estimated to be small, we will verify this explicitly.
- We have previously shown that different infinite-volume regulators can be used to reduce systematic uncertainties. We will explore this further.

Summary of precision goals for next 5-10 years:

HVP: $1\% \rightarrow 0.1\%$

HLbL: $44\% \rightarrow 10\%$

What is required to succeed? We need continued access to large-scale computing resources in the US and dedicated support for the lattice QCD project.